SPECIFICATION

TITLE OF THE INVENTION

A FERROELECTRIC ELEMENT AND A FERROELECTRIC GATE DEVICE

5   USING THE SAME

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to an element and gate

10   device which use a ferroelectric substance, especially to

a ferroelectric element having improved dielectric

polarization retention and squareness ratio, and a

ferroelectric gate device using the same.

15   (2) Description of the Related Art

The recent developments in electronic devices are

driving the need for increasingly larger data capacity.

Nonvolatile memories are attracting attention to maintain

data after power is turned off. There are several types

20   of nonvolatile memories: flash memory, ferroelectric

random-access memory (FeRAM), etc. When handling large

amount of data at a high speed, a device may need a non-

volatile memory which is still faster than these existing

memories. For this reason, ferroelectric gate devices of

25   Metal Ferroelectric Metal Insulator Semiconductor (MFMIS)

type are attracting attention recently. An MFMIS type ferroelectric gate device has the problem of the distribution ratio of the voltage applied to a ferroelectric capacitor (ferroelectric thin film) and gate

5   oxide. This problem will be explained with referring to Fig. 10.

Fig. 10(a) is a diagram of a circuit in which a paraelectric capacitor 101 is serially connected to a ferroelectric capacitor 102. The paraelectric capacitor

10   101 and ferroelectric capacitor 102 shown in Fig. 10(a) represent a gate oxide and a ferroelectric thin film in a ferroelectric gate device, respectively. One terminal of the ferroelectric capacitor 102 is grounded. Now, the voltage Vpp is applied to the terminal IN of the

15   paraelectric capacitor 101. At this time, assume that the voltage at both ends of the ferroelectric capacitor 102 is Vf; the voltage at both ends of the paraelectric capacitor 101 is Vc; and the electric charge induced in each of the paraelectric capacitor 101 and the ferroelectric capacitor

20   102 is Q. The electric charge Q and voltage Vf of the ferroelectric capacitor 102 indicate the hysteresis characteristic as shown in Fig. 10(b). The relationship between the electric charge Q and voltage Vc of the paraelectric capacitor 101 is expressed as Formula 1.

25   $Q = CcVc$

= Cc (Vpp-Vf)   (Formula 1)

The point A (see Fig. 10(b)), which is the intersection of the straight line expressed by Formula 1 and the above-mentioned hysteresis curve, is the operating point at this time.

When the voltage of the terminal IN, to which the voltage Vpp of the paraelectric capacitor 101 is applied, is returned to 0 V, the relationship between the electric charge Q and voltage Vc of the paraelectric capacitor 101 is expressed as Formula 2.

Q = CcVc

= -CcVf   (Formula 2)

The point B (see Fig. 10(b)), which is the intersection of the straight line expressed by Formula 2 and the above-mentioned hysteresis curve, is the operating point at this time. Since the polarization of the ferroelectric substance of the ferroelectric capacitor 102 is retained, the potential of -Vh is retained at the connection node of the paraelectric capacitor 101 and the ferroelectric capacitor 102.

To increase the retained voltage (-Vh), it is desirable to increase the voltage applied to the ferroelectric capacitor 102. However, when a voltage is applied to the terminal IN, a voltage will be also applied to the paraelectric capacitor 101. Therefore, the degree

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of the polarization of the ferroelectric substance does not become high enough. If the voltage applied to Terminal IN is too high, the electric field strength of the paraelectric capacitor 101 exceeds the withstand voltage. The coercive voltage can be increased by increasing the squareness ratio M of the ferroelectric substance (=Pr (remanence) / Ps (spontaneous polarization)) (see Fig. 10(b)). To do so, the crystallinity of the ferroelectric thin film must be improved. However, it is difficult to form a crystal of the ferroelectric thin film having the squareness ratio M as high as a bulk crystal of the ferroelectric substance.

As mentioned above, in the circuit where the paraelectric capacitor 101 and ferroelectric capacitor 102 are serially connected, there is a problem that the voltage retained at the connection node of both the capacitors 101 and 102 cannot be increased because it is difficult to apply a sufficiently high voltage only to a ferroelectric capacitor 102, and the squareness ratio of the ferroelectric thin film is not very large.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to solve the above-mentioned problems. More specifically, the present invention aims to provide a ferroelectric element in which

a switching element serving as a resistor or a capacitor depending on a voltage applied to the switching element is serially connected to a ferroelectric capacitor, and a ferroelectric gate device using the same.

5   A first ferroelectric element of the present invention which achieves the above-mentioned object comprises a ferroelectric capacitor and a switching element serially connected to said ferroelectric capacitor; said switching element comprising a zener

10   diode; when a voltage is applied between both terminals of said ferroelectric element, said switching element serving as a resistor if a voltage higher than the coercive voltage of a ferroelectric substance which said ferroelectric capacitor comprises is applied to said

15   ferroelectric capacitor; and when a voltage is applied between both terminals of said ferroelectric element, said switching element serving as a capacitor if a voltage lower than the coercive voltage of said ferroelectric substance is applied to said ferroelectric capacitor.

20   A second ferroelectric element of the present invention which achieves the above-mentioned object comprises a ferroelectric capacitor and a switching element which comprises an N-channel field-effect transistor and a P-channel field-effect transistor and is

25   serially connected to said ferroelectric capacitor;

sources of said N-channel and P-channel electric field

effect transistors being connected to an input terminal;

drains of said N-channel and P-channel field-effect

transistors being connected to one end of said

5   ferroelectric capacitor; gates of said N-channel and P-

channel field-effect transistors being connected to the

other end of said ferroelectric capacitor; when a voltage

is applied to both terminals of said ferroelectric element,

said switching element serving as a resistor if a voltage

10   higher than the coercive voltage of a ferroelectric

substance which said ferroelectric capacitor comprises is

applied to said ferroelectric capacitor; and when a

voltage is applied to both the terminals of said

ferroelectric element, said switching element serving as a

15   capacitor if a voltage lower than said coercive voltage is

applied to said ferroelectric capacitor.

A third ferroelectric element of the present

invention which achieves the above-mentioned object

comprises a ferroelectric capacitor, a switching element

20   serially connected to said ferroelectric capacitor and a

paraelectric capacitor serially connected to said

ferroelectric capacitor or said switching element; said

switching element comprising a zener diode; when a voltage

is applied to both terminals of said ferroelectric element,

25   said switching element serving as a resistor if a voltage

higher than the coercive voltage of a ferroelectric

substance which said ferroelectric capacitor comprises is

applied to said ferroelectric capacitor; and when a

voltage is applied to both terminals of said ferroelectric

5   element, said switching element serving as a capacitor if

a voltage lower than said coercive voltage is applied to

said ferroelectric capacitor.

The ferroelectric gate device according to the

present invention which achieves the above-mentioned

10   object comprises a ferroelectric capacitor, a switching

element and a field-effect transistor having a source, a

drain and a gate; said ferroelectric capacitor having an

input terminal at one end; the other end of said

ferroelectric capacitor being connected to one end of said

15   switching element; the other end of said switching element

being connected to the gate of said field-effect

transistor; and said switching element comprising a zener

diode.

20   BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 is a circuit diagram of a first embodiment of

the ferroelectric element according to the present

invention.

Fig. 2 is a drawing for illustrating the operation·

25   of the ferroelectric element of Fig. 1.

Fig. 3 is a drawing which shows the simulation result of the relationship between the dielectric polarization and applied voltage in the ferroelectric element of Fig. 1.

Fig. 4 is a circuit diagram of a second embodiment of the ferroelectric element according to the present invention.

Fig. 5 is a drawing showing the simulation result of the relationship between the dielectric polarization and applied voltage in the ferroelectric element of Fig. 4.

Fig. 6 is a circuit diagram of a third embodiment of the ferroelectric element according to the present invention.

Fig. 7 is a drawing which shows the simulation result of the relationship between the applied voltage and output voltage in the ferroelectric element of Fig. 6.

Fig. 8 is a circuit diagram showing one embodiment of the ferroelectric gate device according to the present invention.

Fig. 9 is a drawing which shows the simulation result of the relationship between the drain current and applied voltage in the ferroelectric gate device of Fig. 8.

Figs. 10(a) and (b) are the drawings for illustrating prior art: Fig. 10(a) is the diagram of a circuit in which a ferroelectric capacitor and a

paraelectric capacitor are serially connected; and Fig.
10(b) is a drawing for illustrating the operation of the
circuit shown in Fig. 10(a).

5   DETAILED DESCRIPTION OF THE INVENTION
        Below, the embodiments of the ferroelectric element
according to the present invention and the ferroelectric
gate device using the same are explained with referring to
the accompanying drawings. In this specification, the
10   phrase "gate device" means a switching element represented
by a field-effect transistor. Specifically, the switching
element means an element in which current flow is caused
between its source and drain when ON voltage is applied to
its gate, whereas current flow between its source and
15   drain is substantially stopped when OFF voltage is applied
to its gate.

(First embodiment of the ferroelectric element according
to the present invention)
20   Fig. 1 is a circuit diagram of the first embodiment
of the ferroelectric element according to the present
invention. As shown in Fig. 1, the ferroelectric element
according to this embodiment comprises a ferroelectric
capacitor 1 and a switching element 2 which are connected
25   serially. The switching element 2 is a zener diode. A

zener diode shows the voltage-current characteristics of a normal diode when a forward-biased voltage is applied, while it keeps a voltage between its terminals constant when a reverse-current flows. The switching element 2 has

5   a cathode 2c and an anode 2a. The cathode 2c is connected to the ferroelectric capacitor 1, while the anode 2a is connected to a terminal SS. The zener diode (switching element 2) can be treated as an element having a characteristics similar to a switch. That is, the diode

10   serves as a resistor when the voltage applied is higher than a predetermined level, while it serves as a capacitor when the voltage applied is lower than the predetermined level. The terminal SS of the switching element 2 is grounded and a voltage Vin is applied to the terminal IN

15   of the ferroelectric capacitor 1. In the explanation below, the voltage between both ends of the ferroelectric capacitor 1 is Vf and the voltage between both ends of the switching element 2 is Vr. As a ferroelectric substance of the ferroelectric capacitor 1, for example, strontium

20   bismuth tantalate (Y1:$SrBi_2Ta_2O_9$) can be used.

The operation of the switching element 2 is specifically explained with referring to Figs. 2(a) and 2(b). The switching element 2 serves as a capacitor or a resistor depending on the voltage Vin applied to the input

25   terminal IN and the voltage Vf between both ends of the

ferroelectric capacitor 1. More specifically, the switching element 2 serves as a capacitor when the voltage Vf is lower than the coercive voltage Vc of the ferroelectric substance of the ferroelectric capacitor 1,

5   while it serves as a resistor when the voltage Vf is higher than the coercive voltage Vc. In other words, the switching element 2 is designed to have such characteristics. Therefore, the circuit diagram of the ferroelectric element of Fig. 1 is equivalent to that of

10 Fig. 2(a) when Vf<Vc, while it is equivalent to that of Fig. 2(b) when Vf≥Vc.

When the voltage Vin applied to the input terminal IN is sufficiently higher than the coercive voltage Vc, the voltage higher than the coercive voltage Vc is applied

15 to the ferroelectric capacitor 1. In this case, as already stated, the switching element 2 serves as a resistor. Therefore, the voltage Vf between both ends of the ferroelectric capacitor 1 becomes equal to the applied voltage Vin. Specifically, the voltage Vf (= Vin>Vc)

20 which is higher than the coercive voltage Vc is applied to the ferroelectric capacitor 1. This voltage sufficiently induces the polarization of the ferroelectric substance of the ferroelectric capacitor 1. When the voltage Vin applied to the input terminal IN is lower than the

25 coercive voltage Vc, so is the voltage applied to the

ferroelectric capacitor 1. In this case, the switching element 2 serves as a capacitor, as already stated. This characteristic of the switching element 2 enables retaining the polarization of the ferroelectric substance

5   of the ferroelectric capacitor 1 when a high voltage is applied to the input terminal IN to induce the polarization in the ferroelectric substance of the ferroelectric capacitor 1, and then the voltage Vin is reduced so that the switching element 2 starts to serve as

10   a capacitor. Accordingly the squareness ratio of the ferroelectric capacitor 1 is increased.

A simulation was performed to confirm these improvements in characteristics. Fig. 3 shows the simulation result of the polarization Pr induced in the

15   ferroelectric substance of the ferroelectric capacitor 1. The conditions of the simulation were as follows: the resistance value of the switching element 2 while serving as a resistor was 100 Ω; the capacitance of the switching element 2 while serving as a capacitor was 10 pF; the

20   coercive voltage Vc of the ferroelectric substance of the ferroelectric capacitor 1 was 1.5 V; and the voltage ranging from -10 V to 10 V was applied to the input terminal IN.

Fig. 3 shows the relationship between the voltage

25   Vin applied to the input terminal IN and the polarization

Pr induced by the voltage Vin in two types of elements:
the ferroelectric element equipped with the switching
device 2 according to this embodiment and the element
consisting only of ferroelectric capacitor 1 and not

5   equipped with the switching device 2. As seen from Fig. 3,
when the applied voltage Vin was increased from 0 V, the
polarization of the ferroelectric element according to
this embodiment was reversed at about 6 V. Considering
that the coercive voltage Vc of the ferroelectric

10   capacitor 1 was 1.5 V, the result reveals that the
polarization retention characteristics of the
ferroelectric element according to this embodiment have
been improved. In addition, the ferroelectric capacitor 1
which is not provided with the switching element 2 showed

15   the squareness ratio of 0.77. In comparison, the
ferroelectric element according to this embodiment showed
a much higher ratio, 0.92.

        As mentioned above, connecting of the switching
element 2 to the ferroelectric capacitor 1 serially

20   enabled inducing the polarization in the ferroelectric
substance of the ferroelectric capacitor 1 at a low input
voltage. This also improved the polarization retention
characteristics of the ferroelectric substance of the
ferroelectric capacitor 1. Furthermore, the squareness

25   ratio of the ferroelectric element was greatly increased.

The switching element 2 will perform as long as it fulfills the following two conditions: 1) it is an element whose current value changes steeply in the vicinity of a predetermined voltage value (threshold voltage value); and

5   2) it is designed to have such a threshold voltage that it behaves as a resistor or a capacitor depending on the order of the voltage values (the voltage Vf applied to the ferroelectric capacitor, to which it is serially connected, and the coercive voltage Vc), as described above.

10   Although Y1 was used as the ferroelectric substance of the ferroelectric capacitor 1 above, any kind of material can be used as long as the material has a hysteresis characteristics in polarization. For example, the ferroelectric element may comprise bismuth titanate,

15   lead titanate or the like; high molecular compounds, such as polyvinylidene fluoride-ethylene trifluoride copolymer (P (VDF/TrFE)), which maintain data by using the uneven distribution of electric charge. The use of these substances produces similar effects to the above.

20   Described above is the case where the terminal SS of the switching element 2 is grounded and the voltage Vin is applied to the terminal IN of the ferroelectric capacitor 1. However, the terminal IN may be grounded and the voltage Vin may be applied to the terminal SS. This

25   condition can also produce similar effects to the above.

(Second embodiment of the ferroelectric element according
to the present invention)

Fig. 4 is a circuit diagram of the second embodiment
of the ferroelectric element according to the present
invention. The ferroelectric element of this embodiment
comprises a ferroelectric capacitor 1 and a switching
element which are serially connected. The switching
element is constructed from an N-channel MOS transistor 3
and a P-channel MOS transistor 4. The N-channel MOS
transistor 3 is an N-channel field-effect transistor, and
the P-channel MOS transistor 4 is a P-channel field-effect
transistor. One end of the ferroelectric capacitor 1 and
the drains of the N-channel MOS transistor 3 and the P-
channel MOS transistor 4 are connected to a connection
node CP. The other end of the ferroelectric capacitor 1,
the gate of the N-channel MOS transistor 3 and the gate of
the P-channel MOS transistor 4 are connected to a terminal
SS. The sources of the N-channel MOS transistor 3 and the
P-channel MOS transistor 4 are connected to an input
terminal IN. The terminal SS is grounded. The values of
the threshold voltage of the N-channel and P-channel MOS
transistors 3 and 4 are set equal to the coercive voltage
Vc of the ferroelectric substance of the ferroelectric
capacitor 1. The voltage of the substrate provided with

the N-channel MOS transistor 3 is set at -VPP. The
voltage of the substrate provided with the P-channel MOS
transistor 4 is set at Vpp. Vpp represents the maximum
value of the voltage inputted into the input terminal IN.

5   Setting the voltage of each substrate at Vpp or -Vpp is
for preventing a forward current of a pn junction. The
limit values of the voltage inputted into the input
terminal IN are those needed to sufficiently saturate the
polarization. Examples of the values are indicated in Fig.

10   5. as the voltages of -5 V and 5 V. That is, the limit
values of the voltage inputted into the input terminal IN
are the values corresponding to the points where a pair of
hysteresis curves shown in Fig. 5 meet.

In the description below, Vin represents the voltage

15   applied to the input terminal IN and Vf represents the
voltage between both ends of the ferroelectric capacitor 1,
as in the first embodiment. As the ferroelectric
substance of the ferroelectric capacitor 1, for example,
strontium bismuth tantalate ($Y1:SrBi_2Ta_2O_9$) can be used.

20   The N-channel MOS transistor 3 and P-channel MOS
transistor 4 are designed to operate as follows: when the
voltage Vf between both ends of the ferroelectric
capacitor 1 is not lower than Vc, the N-channel MOS
transistor 3 is turned on; when the voltage Vf is not

25   higher than -Vc, the P-channel MOS transistor 4 is turned

on; and when the voltage Vf is higher than -Vc but lower

than Vc, both of the MOS transistors 3 and 4 are turned

off. In other words, the switching element comprising the

N-channel MOS transistor 3 and P-channel MOS transistor 4

5   serves as a resistor when Vf≥Vc or Vf≤-Vc, whereas it

serves as a capacitor when -Vc<Vf<Vc. Therefore, the

effects similar to those produced by the ferroelectric

element according to the first embodiment are obtained.

A simulation was performed to confirm these effects.

10   Fig. 5 shows the analysis result of the polarization

induced in the ferroelectric capacitor 1. The conditions

of the simulation were as follows: the coercive voltage Vc

of the ferroelectric substance of the ferroelectric

capacitor 1 was 1.5 V; and the voltage applied to the

15   input terminal IN was ranging from -5 V to 5 V. Fig. 5

shows the relationship between the voltage Vin applied to

the input terminal IN and the polarization Pr induced in a

ferroelectric substance in two types of elements: the

ferroelectric element according to this embodiment and the

20   element consisting only of ferroelectric capacitor 1. The

former is provided with the switching element comprising

the N-channel and P-channel MOS transistors 3 and 4, while

the latter is not provided with a switching element. As

seen from Fig. 5, when the applied voltage Vin was

25   increased from 0 V, the polarization of the ferroelectric

element according to this embodiment was reversed at about 3 V. Considering that the coercive voltage Vc of the ferroelectric capacitor 1 was 1.5 V in the simulation, it can be seen that the ferroelectric element according to

5   this embodiment has a higher polarization retention characteristics. This results in a much higher squareness ratio of the ferroelectric element according to this embodiment, 0.95, compared to 0.77 of the ferroelectric capacitor which is not provided with a switching element.

10   As mentioned above, serially connecting the switching element, which comprises the N-channel and P-channel MOS transistors 3 and 4, to the ferroelectric capacitor 1 produces effects similar to those produced by the ferroelectric element of the first embodiment. Such

15   ferroelectric capacitor 1 has the greatly improved retention characteristics of dielectric polarization and squareness ratio.

Above, Y1 was used as the ferroelectric substance of the ferroelectric capacitor 1. However, any material

20   which has a hysteresis characteristics in polarization can be used to construct the ferroelectric element. Examples of such materials include bismuth titanate, lead titanate and high molecular compounds, such as polyvinylidene fluoride-ethylene trifluoride copolymer (P (VDF/TrFE)),

25   which retain data using the uneven distribution of an

electric charge. The ferroelectric element constructed

using such a material produces the effects similar to the

above.

(Third embodiment of the ferroelectric element according

5   to the present invention)

Fig. 6 is a circuit diagram of a third embodiment of

the ferroelectric element according to the present

invention. As shown in Fig. 6, the ferroelectric element

according to this embodiment comprises the ferroelectric

10   element according to the first embodiment shown in Fig. 1

and a paraelectric capacitor 5, which are connected

serially. The terminal IN of the ferroelectric capacitor

1 is an input terminal to which a predetermined voltage

Vin is applied. The terminal SS at the side of the

15   paraelectric capacitor 5 is grounded. An output terminal

OUT is provided at the connection node of a switching

element 2 and the paraelectric capacitor 5. The

capacitance of the paraelectric capacitor 5 is, for

example, 10 pF. The ferroelectric substance of the

20   ferroelectric capacitor 1 is, for example, strontium

bismuth tantalate $(Y1:SrBi_2Ta_2O_9)$.

When the voltage Vin applied to the input terminal

IN is sufficiently higher than the coercive voltage Vc of

the ferroelectric substance of the ferroelectric capacitor

25   1, a voltage greater than the coercive voltage Vc is

applied to the ferroelectric capacitor 1. Thus, as

explained in the description of the first embodiment, the

switching element 2 serves as a resistor. For this reason,

the voltage between the input terminal IN and output

5   terminal OUT is applied only to the ferroelectric

capacitor 1. This induces sufficient polarization in the

ferroelectric substance of the ferroelectric capacitor 1.

When the voltage Vin applied to the input terminal IN is

lower than the coercive voltage Vc, only a voltage lower

10   than Vc is applied to the ferroelectric capacitor 1.

Therefore, the switching element 2 serves as a capacitor.

Specifically, when a high voltage is applied to the input

terminal IN to induce polarization in the ferroelectric

substance in the ferroelectric capacitor 1, and then the

15   voltage Vin is reduced, the switching element 2 serves as

a capacitor and the polarization in the ferroelectric

substance of the ferroelectric capacitor 1 is maintained.

Accordingly, the squareness ratio is increased. This also

increases the voltage maintained at the output terminal

20   OUT.

A simulation was performed in order to confirm these

improvements in characteristics. Fig. 7 shows the

simulation result of the voltage Vout of the output

terminal OUT. The simulation was performed under the

25   following conditions: the resistance value of the

switching element 2 while serving as a resistor was 100 Ω; the capacitance of the switching element 2 while serving as a capacitor was 10 pF; the capacitance of the paraelectric capacitor 5 was 10 pF; the coercive voltage

5   Vc of the ferroelectric substance of the ferroelectric capacitor 1 was 1.5 V; and the voltage applied to the input terminal IN was ranging from -10 V to 10 V.

Fig. 7 shows the relationship between the voltage Vin applied to an input terminal IN and the voltage Vout

10   of an output terminal OUT in two circuits: the circuit of ferroelectric element according to this embodiment and a circuit comprising the ferroelectric capacitor 1 and the paraelectric capacitor 5 which are connected serially. The former comprises the switching element 2, while the

15   latter does not. As seen from Fig. 7, when the voltage Vin applied to the input terminal IN is 0 V, the voltage retained at the ferroelectric elements, i.e., the voltages Vout maintained at the terminal OUT, is about 1.1 V in the circuit comprising the ferroelectric capacitor 1 and the

20   paraelectric capacitor 5, which is not provided with the switching element 2, while it is as high as about 2.6 V in the ferroelectric element according to this embodiment. This is because the squareness ratio is increased by serially connecting the switching element 2 to the

25   ferroelectric capacitor 1, as explained in connection with

the ferroelectric element according to the first embodiment.

As mentioned above, the paraelectric capacitor 5 is serially connected to the switching element 2 of the ferroelectric element according to the first embodiment. Thus-constructed circuit forms another ferroelectric element as a whole. This arrangement can increase the voltage Vout retained at the connecting terminal OUT between the switching element 2 and the paraelectric capacitor 5.

Explained above is the case where the switching element 2 and the paraelectric capacitor 5 are connected. However, the ferroelectric capacitor 1 and the switching element 2 may be interchanged, the ferroelectric capacitor 1 and the paraelectric capacitor 5 may be connected, and their connection node may be used as the output terminal OUT. Alternatively, the ferroelectric capacitor 1 and the switching element 2, with their positional relationship maintained, may be interchanged with the paraelectric capacitor 5, the ferroelectric capacitor 1 may be connected to the paraelectric capacitor 5, and their connection node may be used as the output terminal OUT. Further, the ferroelectric capacitor 1 may be interchanged with the switching element 2, the ferroelectric capacitor 1 and the switching element 2 may be interchanged with the

paraelectric capacitor 5, the switching element 2 may be connected to the paraelectric capacitor 5, and their connection node may be used as the output terminal OUT. Any of these arrangements can produce effects similar to those mentioned above.

(An embodiment of the ferroelectric gate device according to the present invention)

Fig. 8 is a circuit diagram showing one embodiment of the ferroelectric gate device of the invention. The gate device according to this embodiment comprises the ferroelectric element shown in Fig. 1 and a MOS transistor 6. The ferroelectric element comprises a zener diode, i.e., a switching element 2, whose anode 2a is connected to the gate of the transistor. A terminal FG is provided at the connection node of the switching element 2 and the gate of the MOS transistor 6. The supply voltage Vdd of 1.0 V is applied to the drain of the MOS transistor 6. The source and substrate of the MOS transistor 6 are grounded. An example of transistors which are usable as the MOS transistor 6 is an N-channel MOS transistor having a gate length of 0.5 μm, a gate width of 5μm and a threshold voltage 0.6 V. An example of materials which are usable as a ferroelectric substance in the ferroelectric capacitor 1 is strontium bismuth tantalate (Y1:$SrBi_2Ta_2O_9$). The area of a ferroelectric substance can

be about 1/10 the area of the gate of the MOS transistor 6.

A simulation was performed in order to analyze the drain current Ids of the MOS transistor 6. Fig. 9 shows the result of the simulation. The simulation was

5   performed under the following conditions: the resistance value of the switching element 2 while serving as a resistor was 100 Ω; the capacitance of the switching element 2 while serving as a capacitor was 10 pF; the coercive voltage Vc of the ferroelectric substance of the

10   ferroelectric capacitor 1 was 1.5 V; and the voltage applied to the input terminal IN was ranging from -10 V to 10 V.

Fig. 9 shows the relationship between the voltage Vin applied to the input terminal IN and the drain current

15   Ids in two gate devices: the ferroelectric gate device according to this embodiment, and a conventional gate device having an MFMIS structure. The former is provided with the switching element 2, while the latter is not, but only the ferroelectric capacitor 1 is connected to its

20   gate. As seen from Fig. 9, the memory window W1 of the conventional gate device having an MFMIS structure was about 3.1 V, while the memory window W2 of the ferroelectric gate device according to this embodiment was as high as about 10.7 V. This is because of the same

25   reason explained above with regard to the third embodiment

of the ferroelectric element according to the present

invention. Namely, it is because the ferroelectric gate

device according to this embodiment has an increased

voltage retained at the terminal FG, which gives the gate

5   device a broader variable range of the threshold voltage

of the MOS transistor 6 than that of the conventional

device with an MFMIS structure.

The memory window W2 of the ferroelectric gate

device according to this embodiment is preferably twice to

10   fifth as high as the memory window W1 of the conventional

gate device having an MFMIS structure. If this ratio is

less than twice, the effects of the invention cannot be

fully exerted, while the ratio higher than fifth may be

difficult to achieve in terms of design.

15   As mentioned above, the ferroelectric gate device

according to this embodiment has a larger memory window

than the conventional gate device having an MFMIS

structure.

Explained above is the case where the switching

20   element 2 is connected to the gate of the MOS transistor 6.

However, the ferroelectric capacitor 1 and the switching

element 2 may be interchanged; the ferroelectric capacitor

1 may be connected to the gate of the MOS transistor 6;

and their connection node may be used as the terminal FG.

25   This arrangement can also produce effects similar to those

mentioned above.

(INDUSTRIAL APPLICABILITY)

The present invention can provide a ferroelectric
5   element which can induce polarization in its ferroelectric
substance with a lower input voltage than conventional
devices and has improved ferroelectric polarization
retention characteristics and squareness ratio. Using
this ferroelectric element for a gate device enables
10   inducing polarization in a ferroelectric substance with a
lower input voltage than in conventional MFMIS type
ferroelectric gate devices. Thus, a ferroelectric gate
device having improved dielectric polarization retention
characteristics, squareness ratio and memory window can be
15   provided.